Development of a Laser Micromachining Process for the Fabrication of SiC Mirrors

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PROGRAM GOALS

1. Demonstrate laser mirror shaping for SCATS telescope.
2. Show compatibility of laser machining with final polishing.
3. Demonstrate ability to micromachine attachment points for SiC mirror mounts.
4. Explore damage mitigation.
5. Model of laser ablation.

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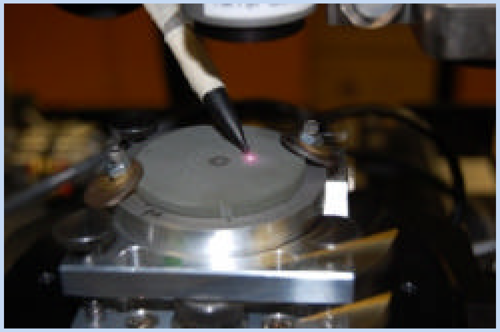
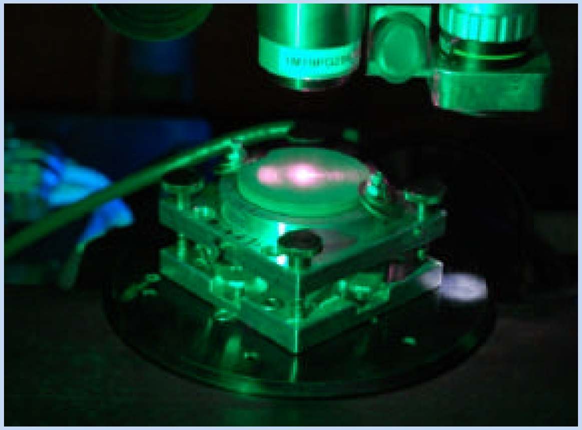
LASER AND MATERIALS

- Picosecond pulsed laser for direct ablation
  - Direct ablation by Coulomb explosion
  - Avoids thermal effects
  - Damage free



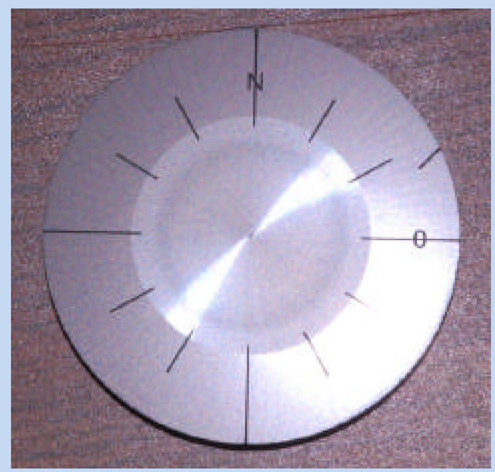
- Two SiC materials studied
  - Trex SiC
  - Poco SuperSiC



1. SCATS MIRROR SHAPING

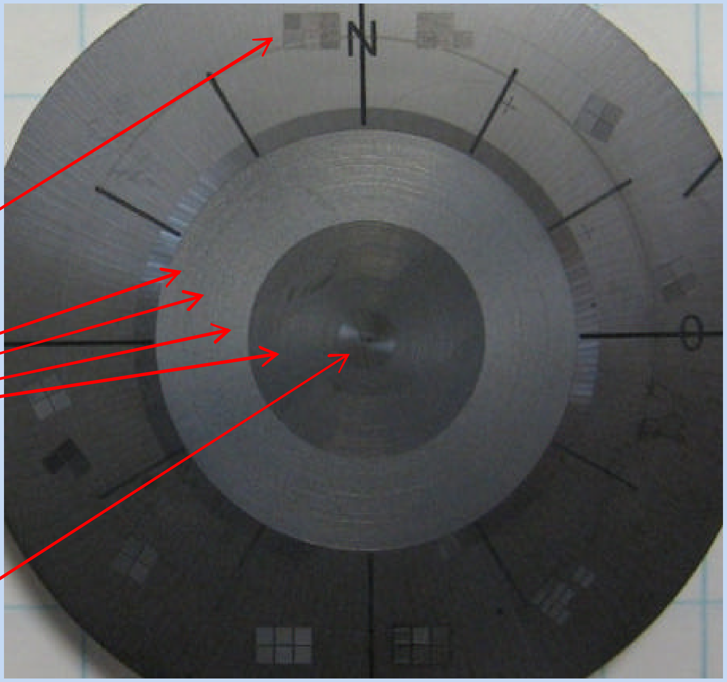
Ultimate goal is to shape SCATS primary and tertiary mirrors.

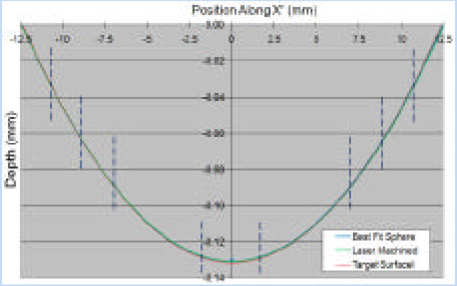
- Primary is an off-axis parabola. At 10” diameter it is too large for our workstation. Red spot shows the location of the 1” diameter subaperture we seek to reproduce.
- Equation for asheric shape of supaperture is specified by formula.
- Before laser ablation, a best-fit-sphere (BFS) was ground into the part (by EOC) to remove the majority of material.
- Laser was then used to remove final few microns, adjusting surface to precise shape.



MIRROR LASER MACHINING PROCESS

- Metrology characterizing shape after BFS grinding is used in conjunction with equation for intended final shape to produce laser guidance algorithm to machine the mirror.
- Ablation rate calibrated sample edge.
- Machining conducted in four concentric sections with z-height adjustments between sections as needed.
- The central portion (1.7 mm radius) cannot be reached while the rotation stage is on center.





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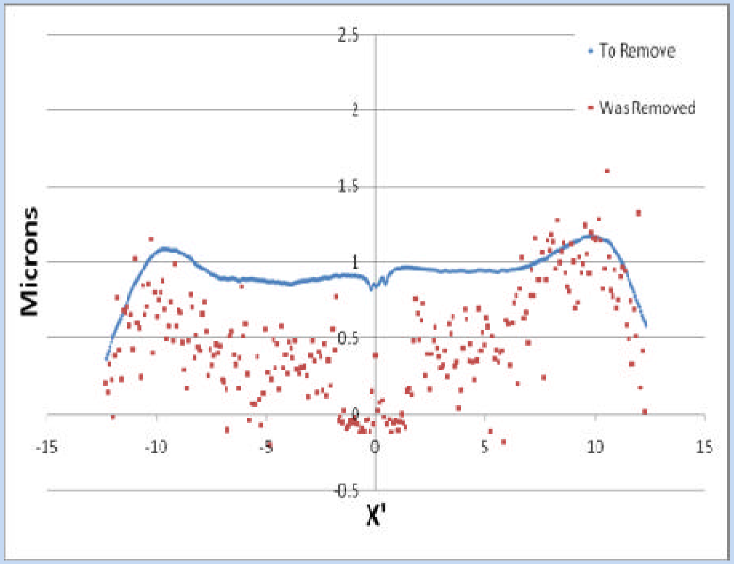
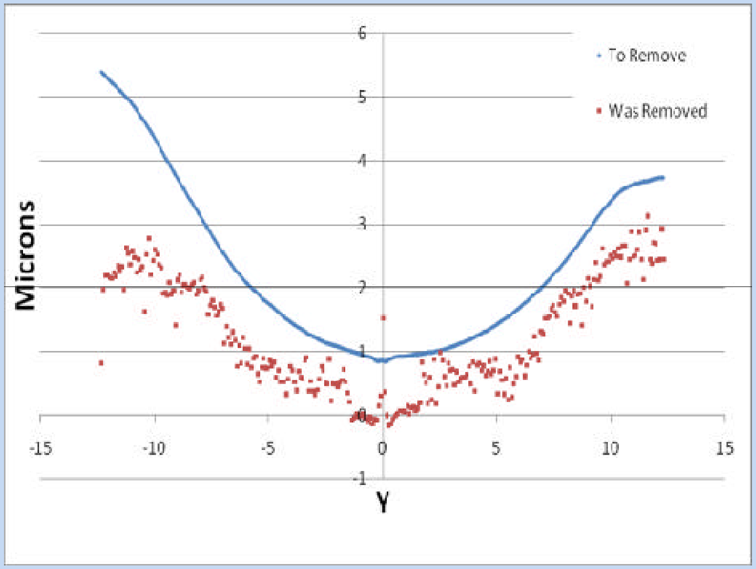
MACHINING ACCURACY

- The critical measure of machining accuracy is how closely the material removal matches that which is calculated to be removed.
- The profile plots below show the calculated amount of material to remove (blue) and the actual material removed.
- Algorithm and hardware are functioning well. Removal is slightly less than calculated, which leaves and intentional buffer for finish polish.

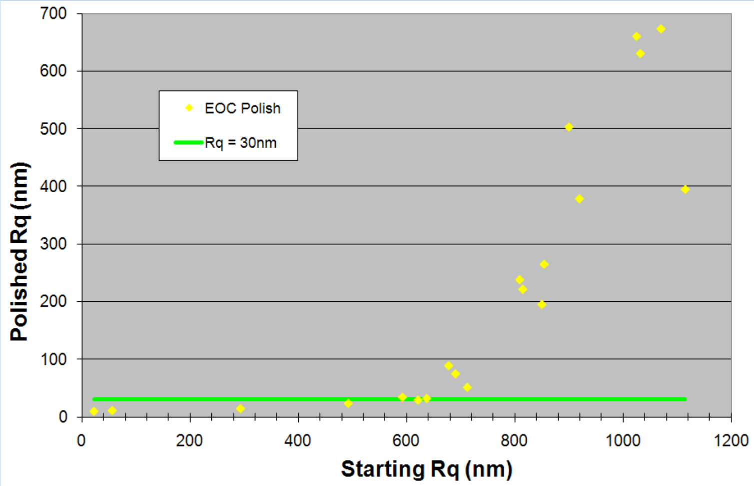




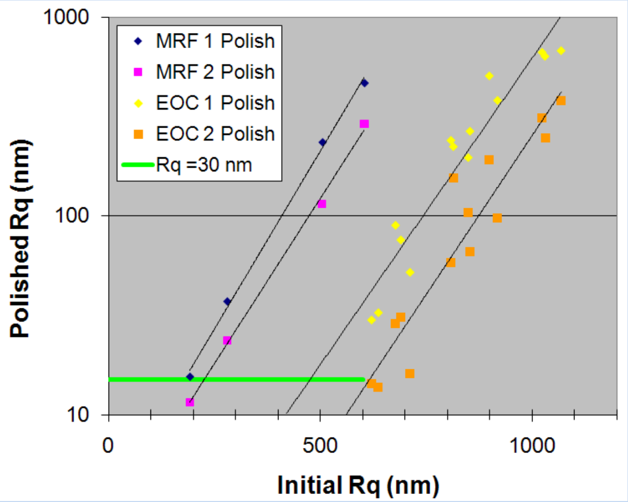
2. POLISHING COMPATIBILITY

Determined how much laser induced roughness can be tolerated by a final polishing process.

- Processed laser ablated SiC with by MRF (QED) or polymer belt (EOC) processes.
- Post-polish roughness plotted vs. Pre-polish roughness.



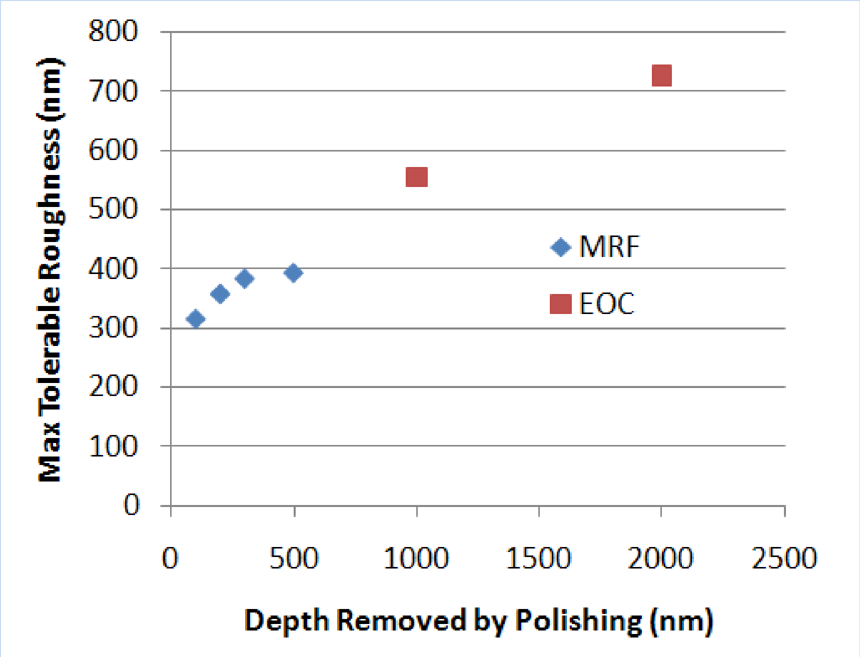
Green line is 30 nm or ~ $\lambda/20$.



Linear fits cross line at max acceptable laser induced roughness.

2. POLISHING COMPATIBILITY

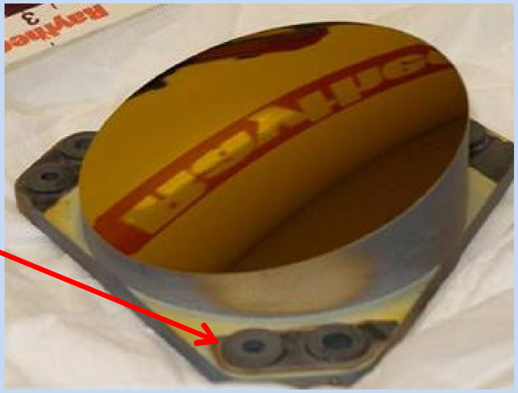
- More smoothing can be achieved if willing to remove more material by polishing.
- Plot shows how much material must be left to remediate given amounts of laser induced roughness.
- In order achieve final mirror shape, some material above the final shape must be left behind for the polisher to work with.



3. ATTACHMENT POINT MACHINING

Attachment points on SiC optical benches may need:

- Submicron height accuracy,
- Local correction after mirror is finished,
- Avoidance of damage.



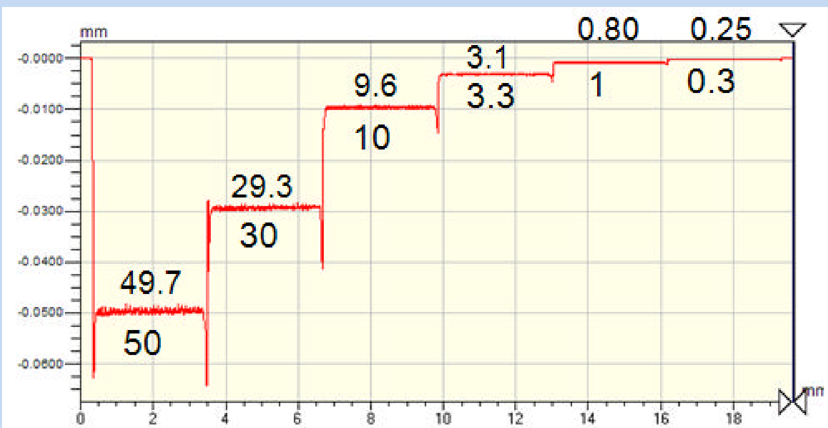
Laser machining has been demonstrated as a viable solution.

- Non-contact method, avoids damage (see later in this presentation).
- Can target anywhere there is a line of sight.
- Arbitrary shape capability.
- Machine to better than 1 µm accuracy in a single preprogrammed operation.
- Machine to better than 0.1 µm accuracy with second machining iteration.

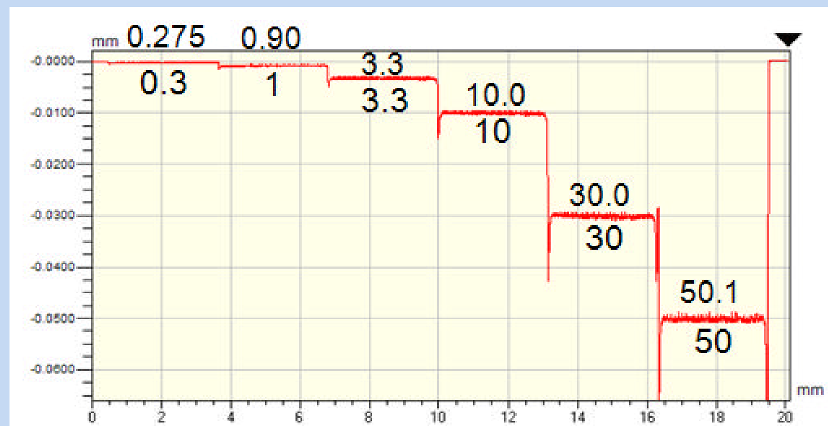
3. ATTACHMENT POINT MACHINING

Example:

- Stair steps were machined into Trex SiC to show accurate height adjustment from 0.3 to 50 microns.
- Number below step is nominal targeted height.
- Number above step is actual machined height.



1st iteration at 1.8 mm^3/hr
All steps within 1 μm of tolerance.

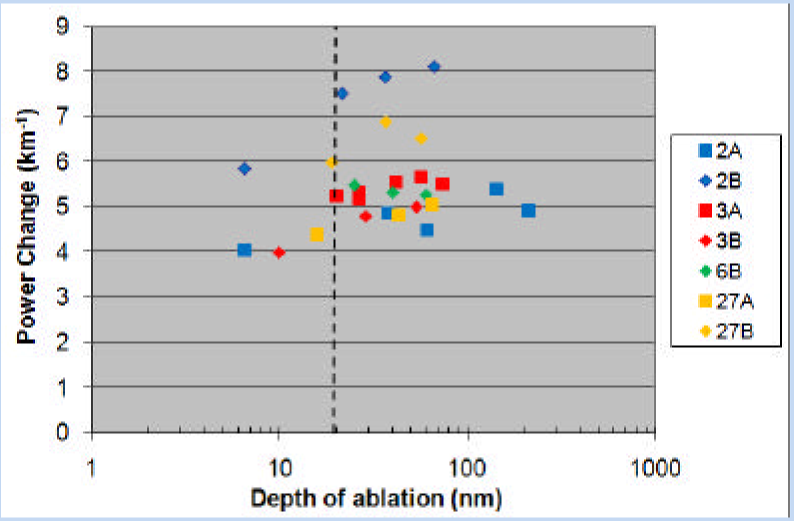


Correction at 0.2 mm^3/hr
All steps within 0.1 μm of tolerance.

4. DAMAGE MITIGATION

Twyman studies show that laser ablation reduces surface stress (therefore damage) in SiC.

- SiC disks prepared by double-side polishing with 1 µm grit.
  (Prepared by Dr. Joe Randi at EOC.)
- Ablated with picosecond laser. Shape measured by interferometry.
- Change in optical power due to stress relief plotted as a function of ablation depth
- Trend is that nearly all stress is relieved with only ~20 to 50 µm of material removed.
- Compare with published studies on similar samples processed by RAP or MRF in which ~150 - 200 nm had to be removed to achieve full stress relaxation.



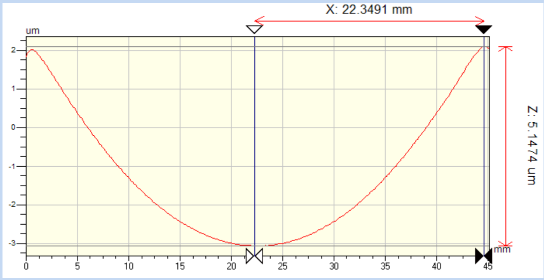
STUDY OF ROUGHER TWYMAN DISKS

Can laser ablation address damage on rougher specimens?

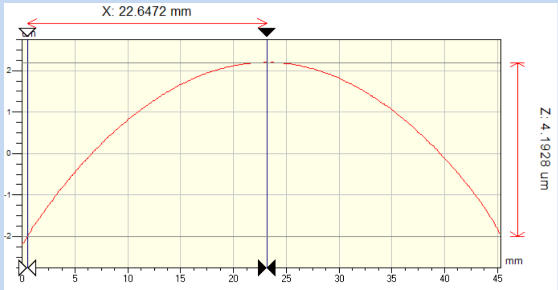
Twyman disks prepared w/ 3 µm grit on one side and 6 µm grit on the other.

- 6 µm face starts with twice the damage, thus twice the stress $\rightarrow$ Disk starts curved away from the rougher face.
- Ablated 4.5 µm of material from the rough face with an aggressive marking laser. (Not the gentle picosecond laser.)
- Curvature of the disk flipped $\rightarrow$ consistent with all stress relieved on rough 6 µm face. Stress on the 3 µm face now responsible for distortion.
- Strongly suggests that even aggressive laser ablation can mitigate damage on conventionally processed SiC.

K = +22.5 km^{-1} before ablation



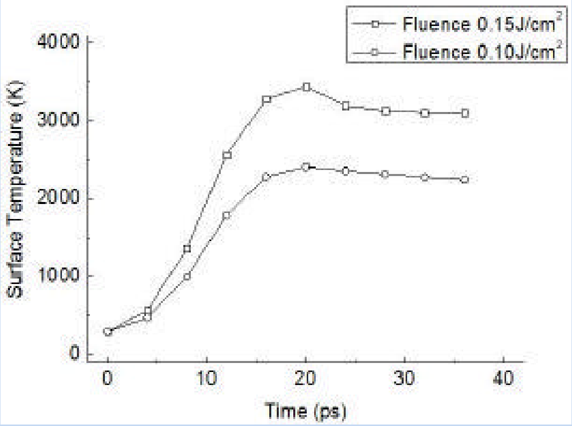
K = -15.1 km^{-1} after ablation

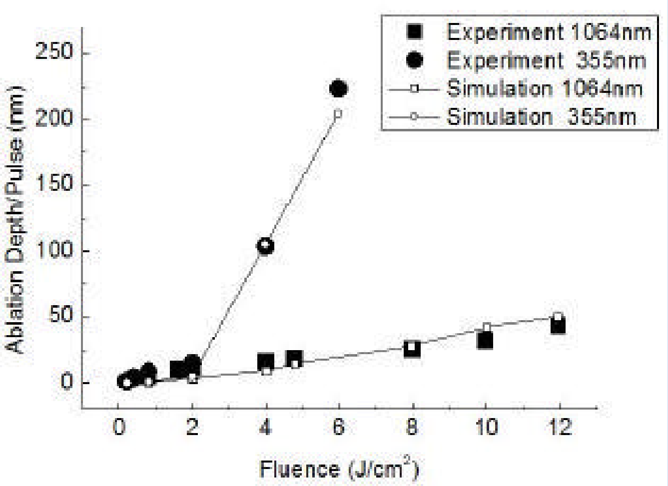


5. MODELING OF LASER ABLATION

Goal is to eventually help in selection of industrial laser system for conducting laser machining of mirrors.

- Dr. Benxin Wu at IIT converted his previously published model of picosecond ablation in metals to apply to SiC.
- Plots of ablation depth vs. fluence are reasonable fits to data collected at MLPC at IR (1064 nm) and UV (355 nm) wavelengths.
- Surface evaporation mechanism matches IR data.
- Critical point phase separation mechanism matches UV data.
- A journal publication has been submitted the open literature.





CONCLUSIONS

1. Mirror shaping is a work in progress. Laser path guidance is working well, but still have to demonstrate on larger mirror and have a part go through final polish.
2. Compatibility of laser machining with final polishing quantified.
3. Ability to micromachining attachment points for SiC mirror mounts demonstrated and commercial transition opportunity expected.
4. Damage mitigation capability of laser ablation demonstrated in Twyman studies .
5. Model of picosecond laser ablation developed and submitted for publication.